The ultimate challenge: Mitigating harmful algal blooms in a world experiencing human nutrient enrichment and climatic change

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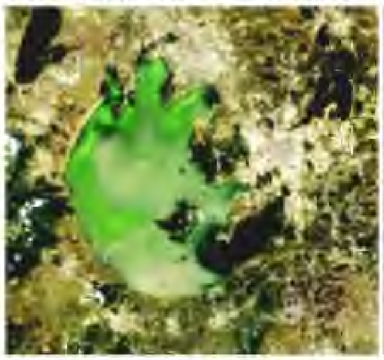
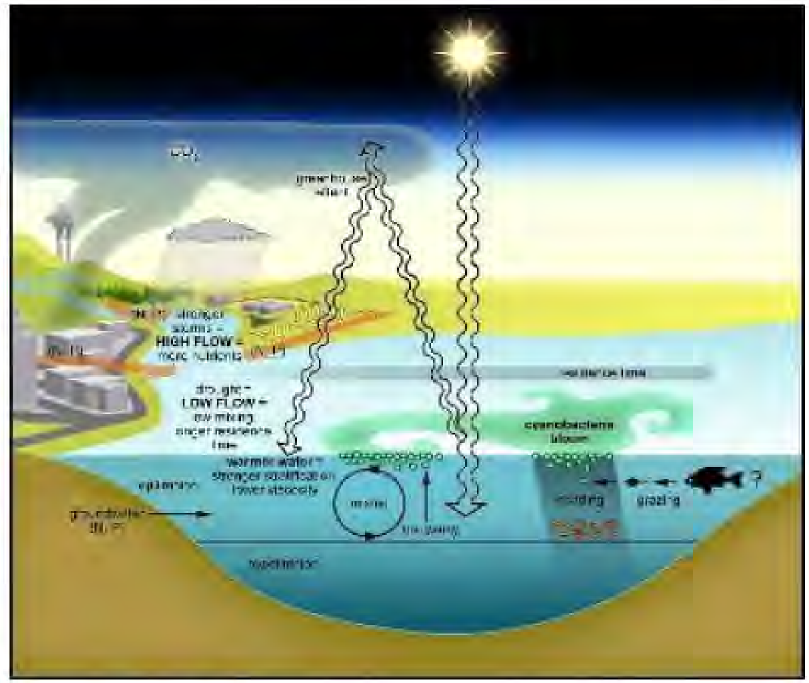






US EPA Region 9 Harmful Algal Bloom Workshop: 25-27 April, 2017

Cyanobacterial Harmful Blooms (CyanoHABs): Symptomatic of human and climatic alteration of aquatic environments

Urban, agricultural and industrial expansion

↓

Increasing nutrient (Nitrogen & Phosphorus) inputs

↓

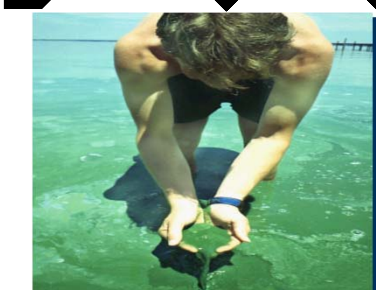
Water use and hydrologic modification play roles

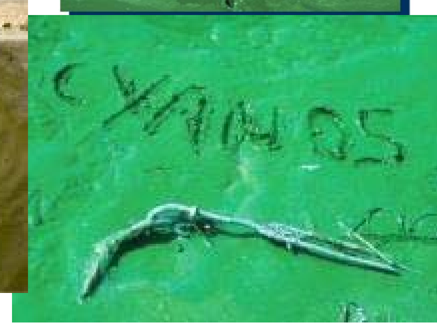
↓

Climate (change) plays a key interactive role

Blooms are intensifying and spreading

↙ ↓ ↘





It's a global problem



- **Freshwater Ecosystems**

(lakes, reservoirs, rivers)

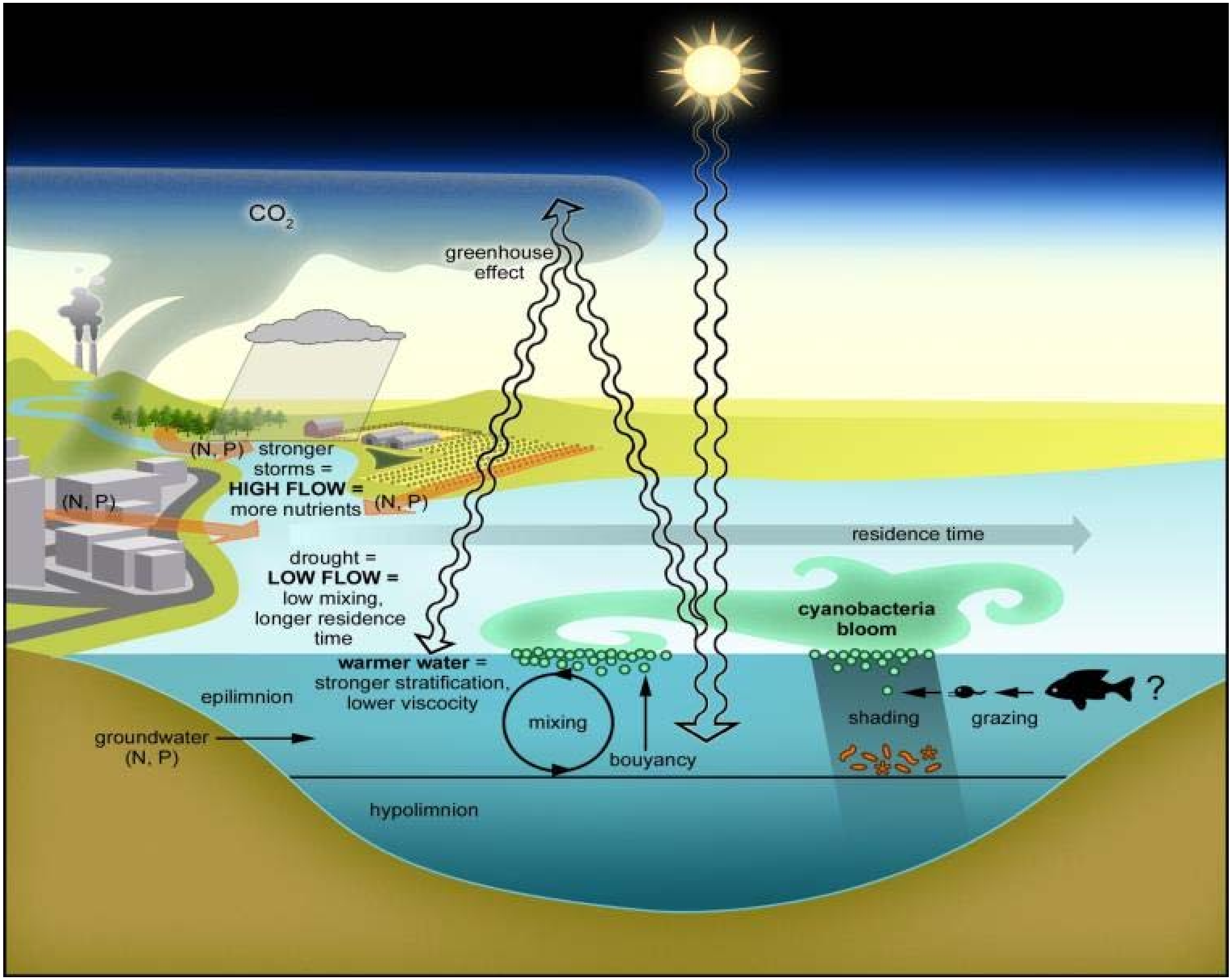


- **Estuaries**



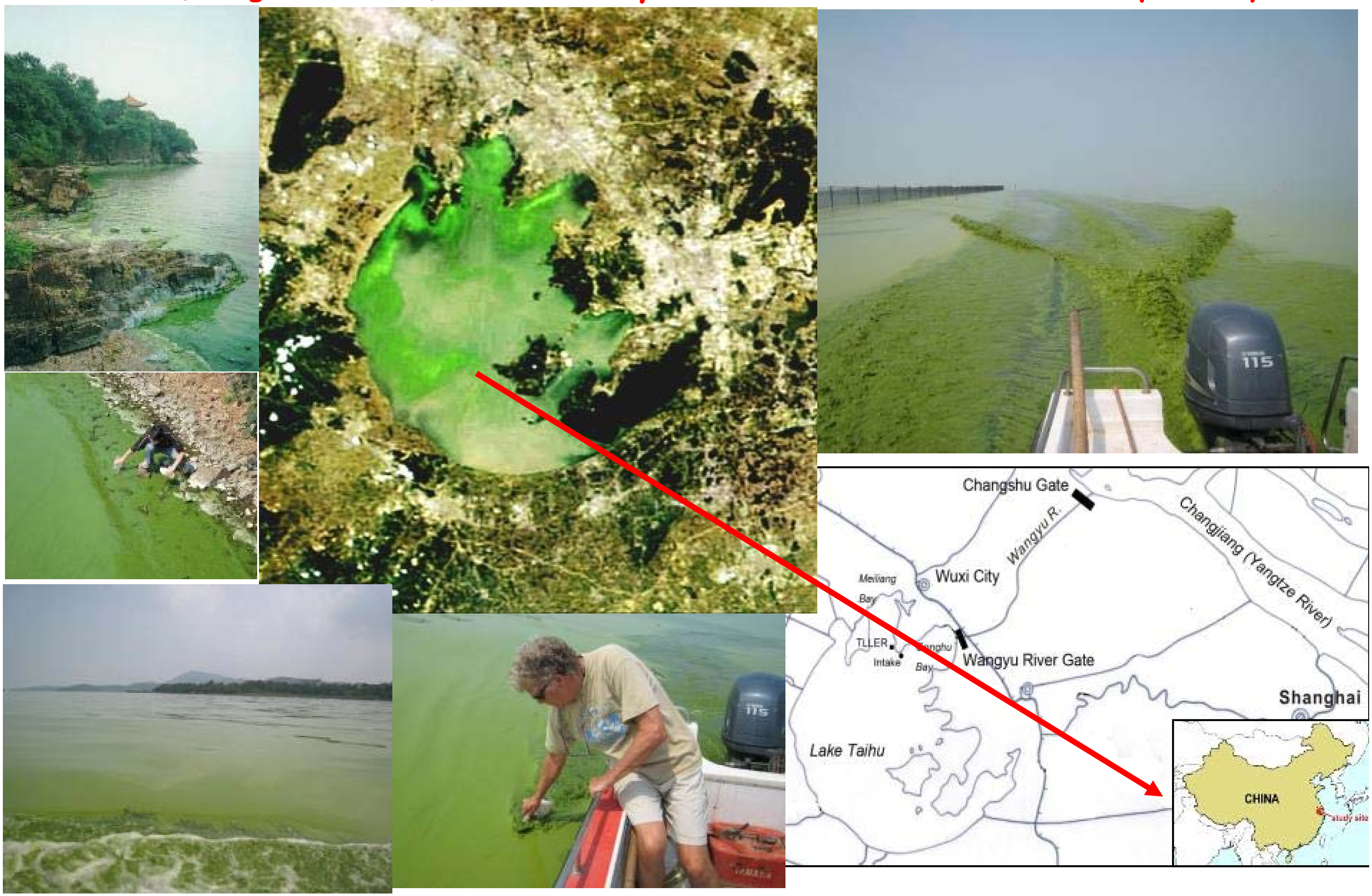
- **Coastal waters & seas**

What Controls CyanoHABs? Interacting Physical, Chemical & Biotic Factors



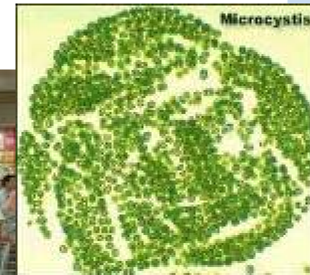
The "poster child": Lake Taihu 3rd largest lake in China.

Nutrients (Lots!) associated with unprecedented human development in the Taihu Basin (Jiangsu Province). Results: Cyano blooms have increased to "pea soup"

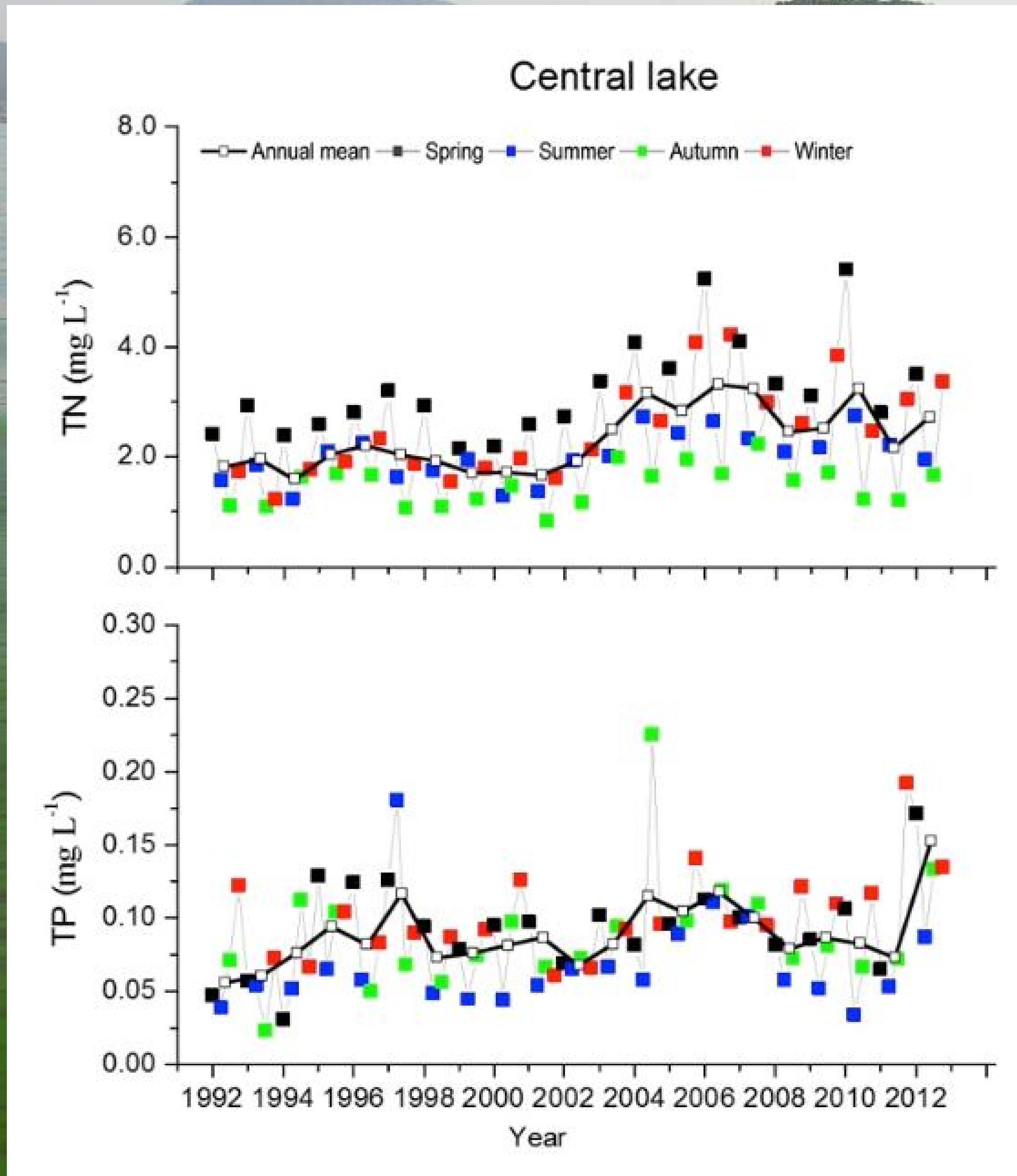


The water cris<u>es</u> (2007- ?) in the Taihu Basin:

- **Cessation drinking water use for >20 million (hepato- and neuro-toxins)**
- **Curtailed recreational use (contact dermatitis)**
- **↓ Fisheries (commercial and recreational)**
- **↓ Tourism**



Recent history of nutrient (TN, TP) increases in Lake Taihu 1992-2012

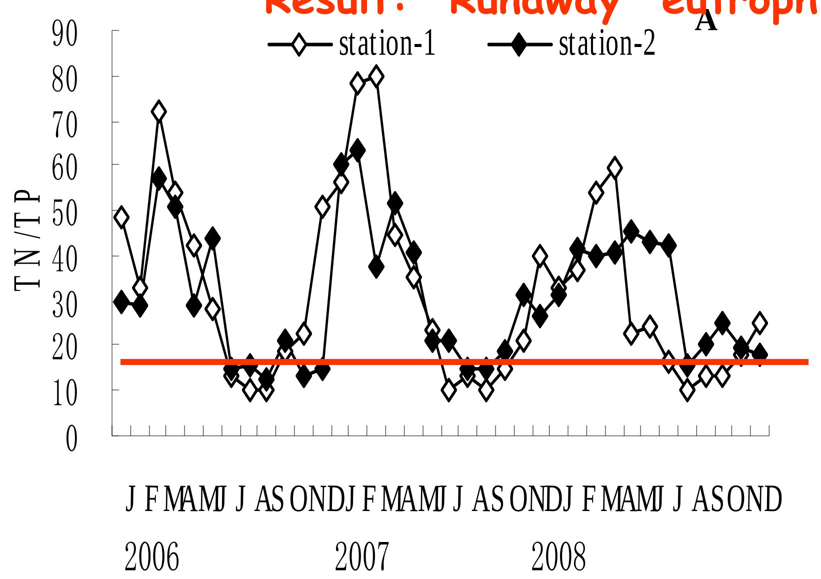


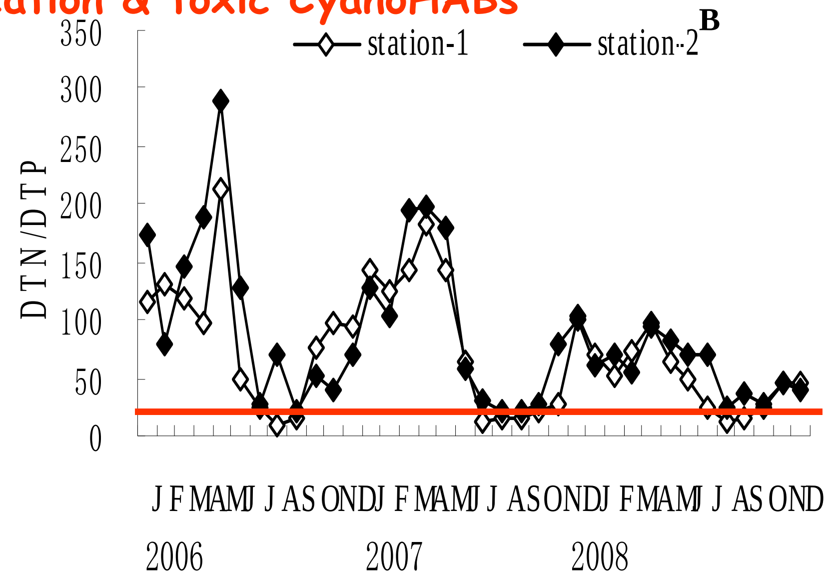
Qin et al., 2010
Xu et al., 2015

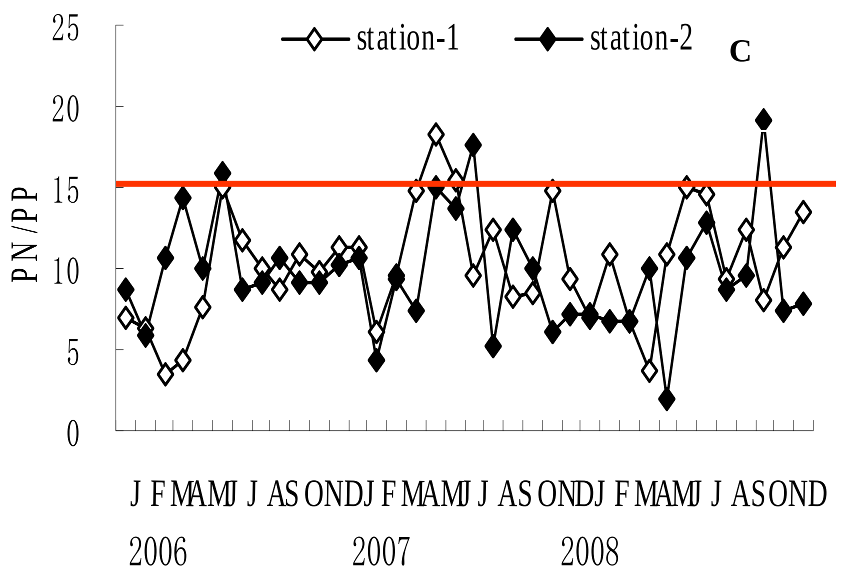
The "nutrient problem" in Taihu in a nutshell

N & P inputs exceed what's needed for balanced algal growth.

Result: "Runaway" eutrophication & toxic CyanoHABs







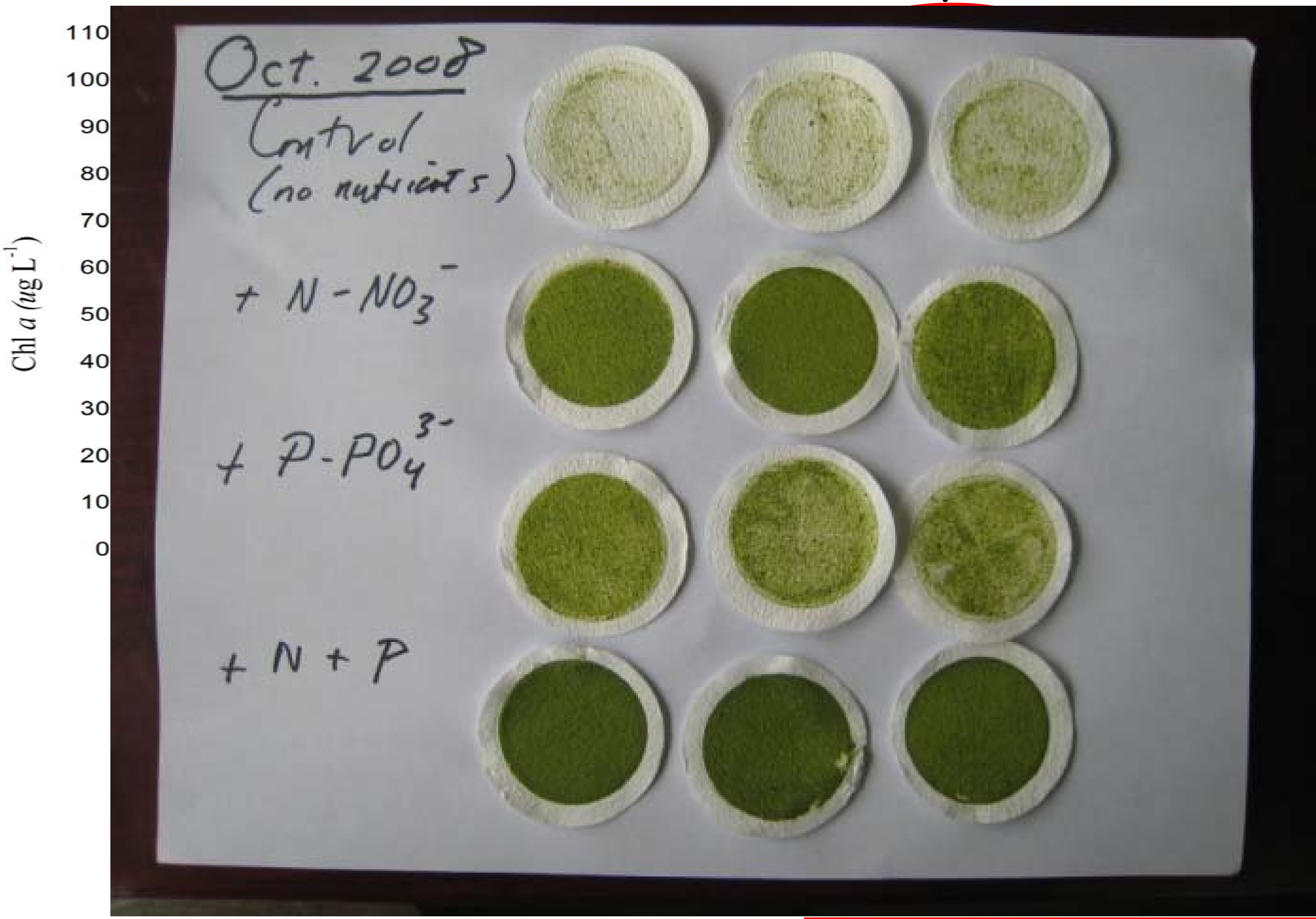
Nutrient (N&P) ratios in Taihu

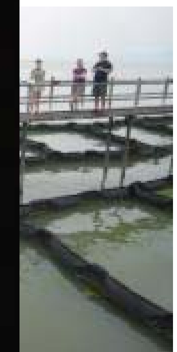
Redfield (balanced growth)
~15:1 (N:P)

HYPOTHESIS
Dual (N & P) reductions will be needed to stem eutrophication and CyanoHABs

Xu et al., 2010

Effects of nutrient (N & P) additions on phytoplankton production (Chl *a*) in Lake Taihu, China: **Both N & P inputs matter!!**





Xu et al. 2010; Paerl et al. 2011

Using nutrient dilution bioassays to determine N&P reductions needed to control blooms

Sampling | **Distribution** | **Nutrient addition** | **Incubation**

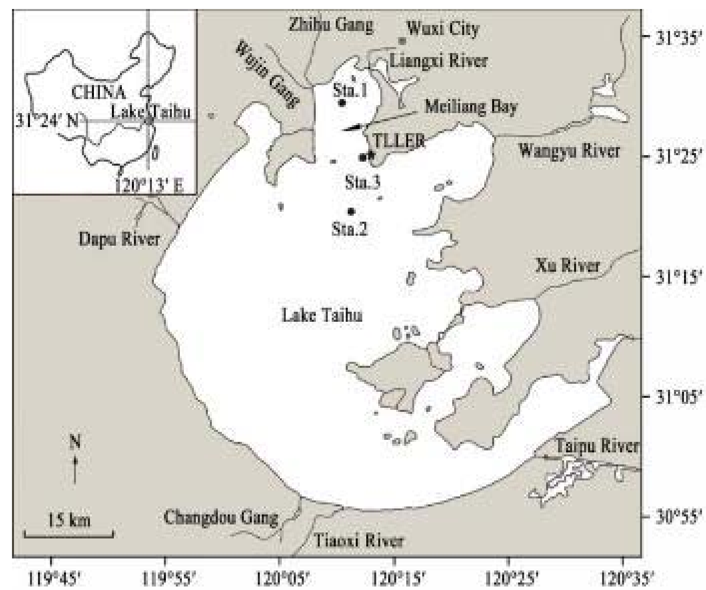
Nutrient dilution bioassays:

1. 0% (lake water, no dilution)
2. 30% dilution
3. 50% dilution
4. 70% dilution

N was added as KNO_3, and P was added as $K_2HPO_4 \cdot 3H_2O$.

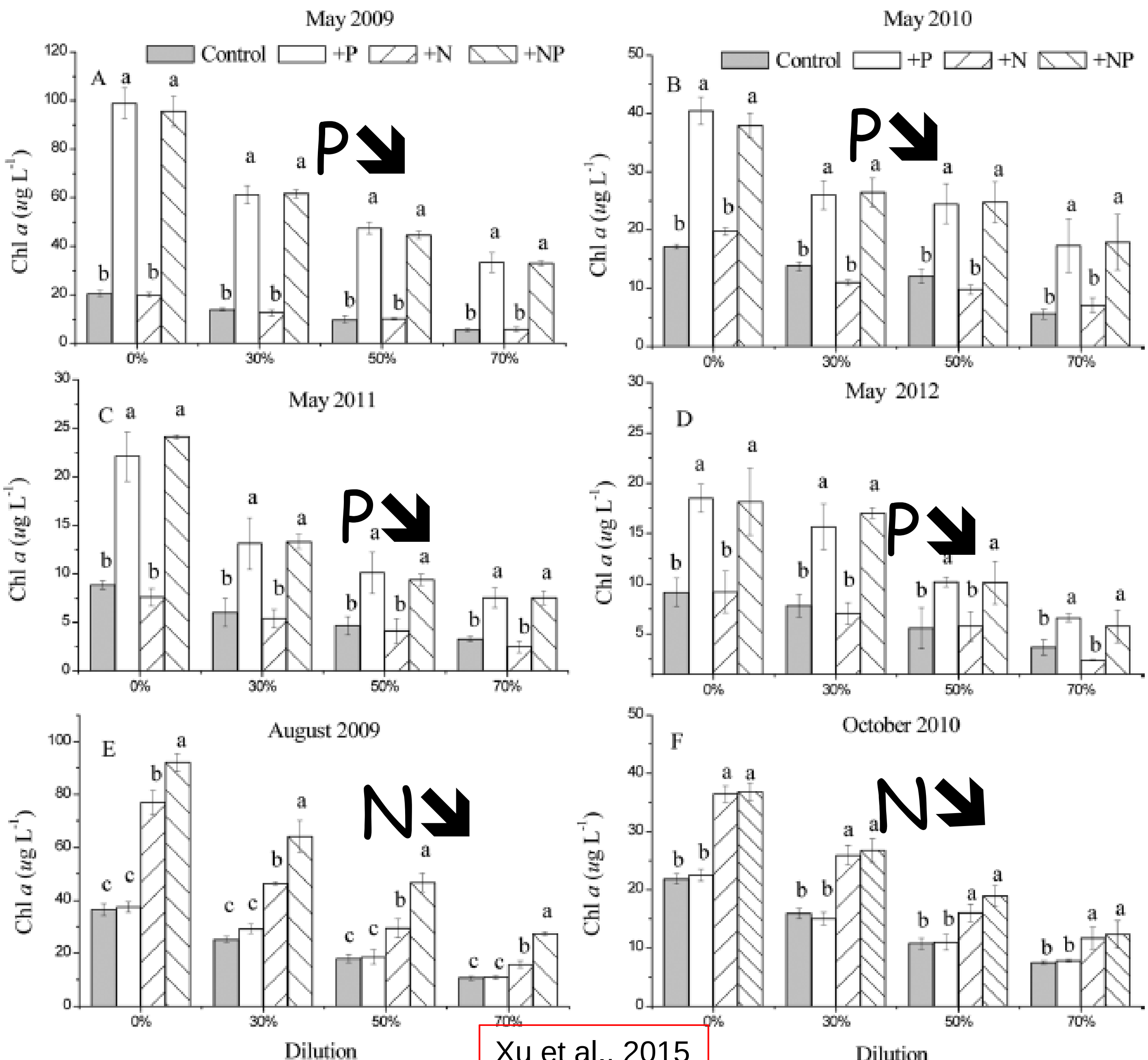
Containers were incubated in the surface water to maintain ambient conditions.

Testing fast response of phytoplankton to the change in ambient conditions



Xu et al., 2015

Nutrient Dilution Bioassays: How much N & P reduction is needed to control blooms?



30-50% for P

50-70% for N

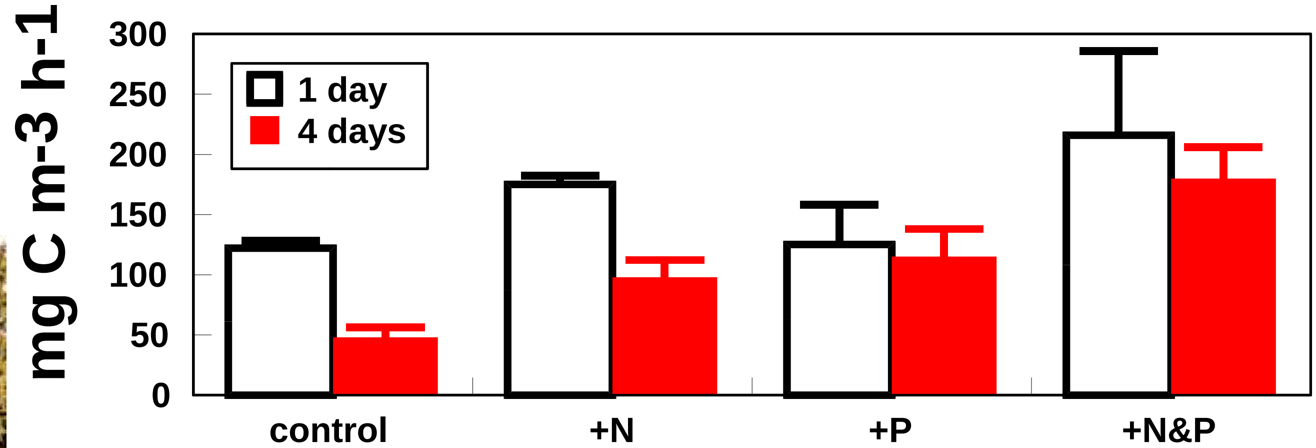
Xu et al., 2015

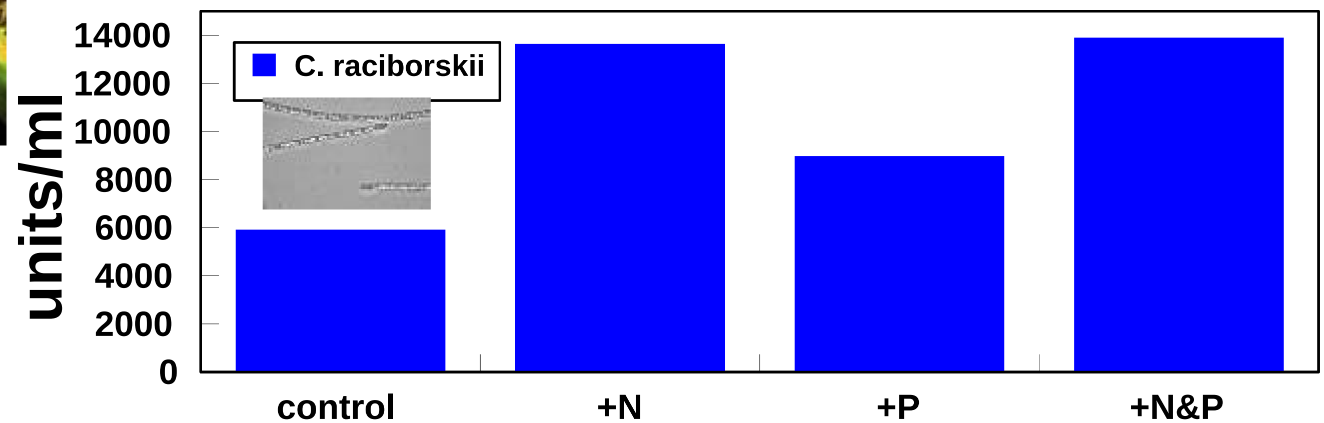
Is Taihu a "looking glass" for eutrophying large lake and coastal ecosystems worldwide?

Florida lakes : *Cylindrospermopsis raciborskii*, rapidly-proliferating, toxic N_2 fixing cyanoHAB

- High P uptake and storage capacity
- High NH_4^+ uptake affinity (competes well for N)
  - N additions (NO_3^- + NH_4^+) often significantly increase growth (chl *a* and cell counts) and productivity
- N_2 fixer (can supply its own N needs)
- Tolerates low light intensities
  - Eutrophication/decreased transparency favors *Cylindro*
  - Often in water column with other cyanoHABs

St. Johns R. System, Florida, USA: N-NO_3 and P-PO_4 effects on CyanoHAB growth and bloom potential (*Cylindrospermopsis raciborskii*)





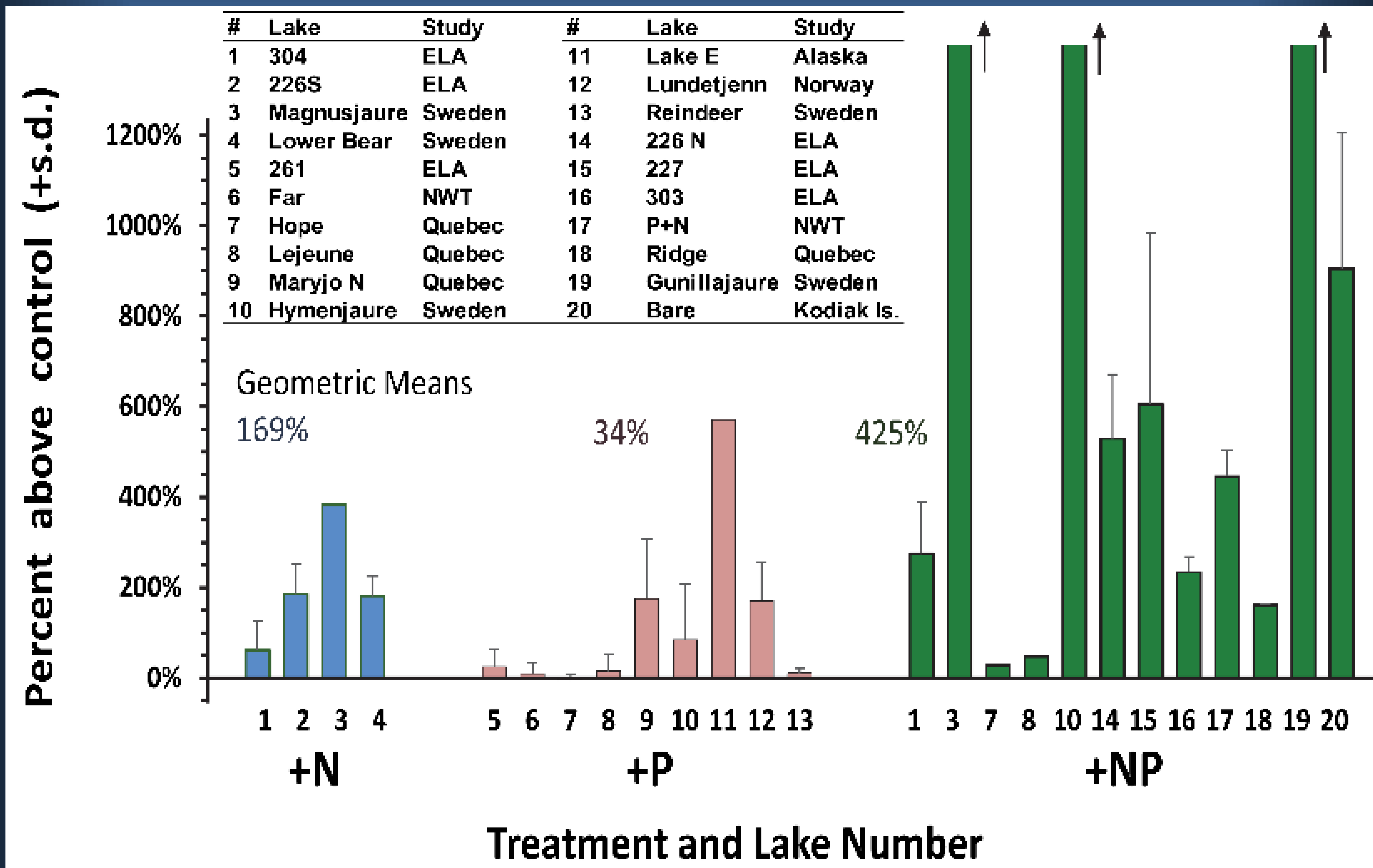
Take home message: *Cylindrospermopsis raciborskii* is highly opportunistic
<u>Dual N & P input constraints will likely be needed to control it</u>

Piehler et al, 2009

What about Lake Erie?

J. Chaffin et al., (2013) "Nitrogen Constrains the Growth of Late Summer Cyanobacterial Blooms in Lake Erie" *Advances in Microbiology* 3, 16-26.

Lets ask the lakes? Whole-Lake Fertilization Experiments (ELA, Quebec, NWT, Sweden)

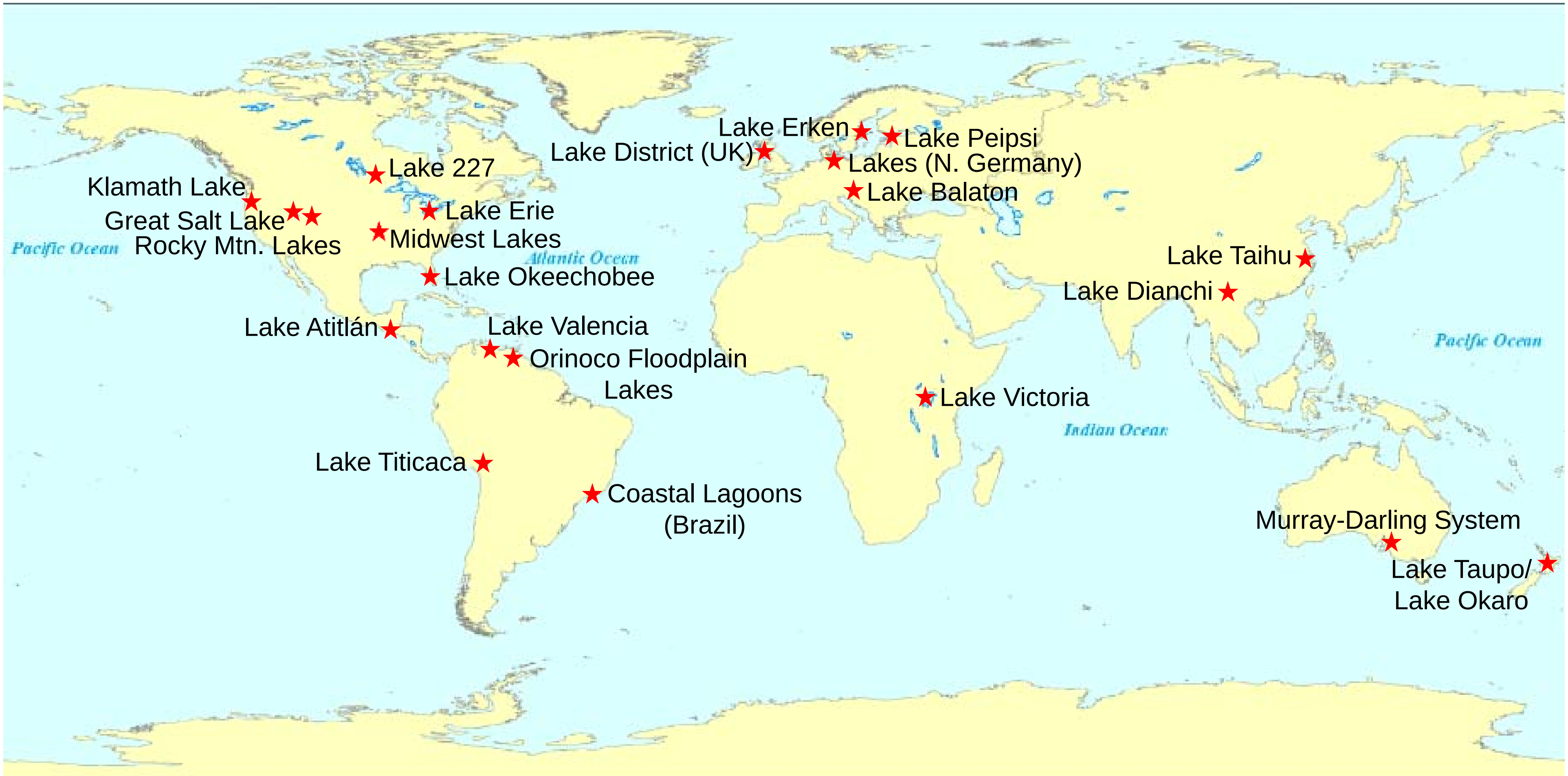


#	Lake	Study	#	Lake	Study
1	304	ELA	11	Lake E	Alaska
2	226S	ELA	12	Lundetjenn	Norway
3	Magnusjaure	Sweden	13	Reindeer	Sweden
4	Lower Bear	Sweden	14	226 N	ELA
5	261	ELA	15	227	ELA
6	Far	NWT	16	303	ELA
7	Hope	Quebec	17	P+N	NWT
8	Lejeune	Quebec	18	Ridge	Quebec
9	Maryjo N	Quebec	19	Gunillajaure	Sweden
10	Hymenjaure	Sweden	20	Bare	Kodiak Is.

Co-Limitation Dominant

Wurtsbaugh et al., 2012; Paerl et al., 2016

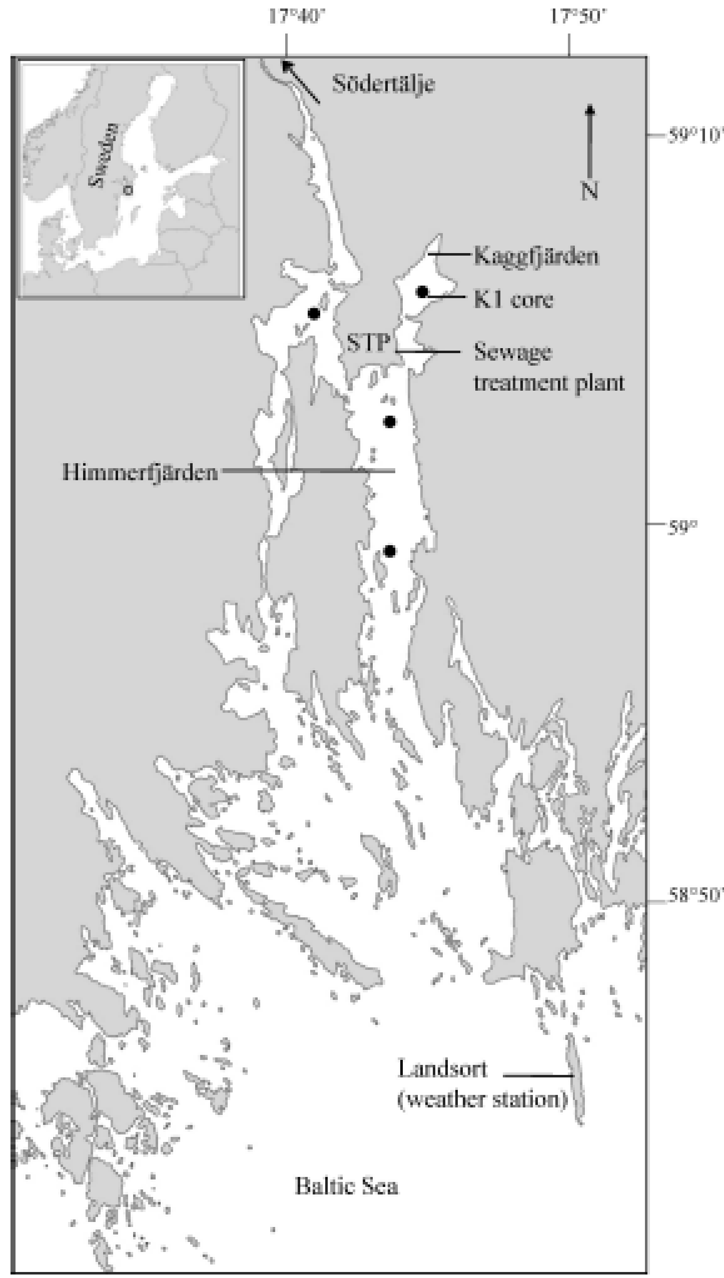
Large lakes and reservoirs in which algal blooms (mostly cyanobacteria) have been shown to be N & P stimulated



Sources: Havens et al., 2003; Elser et al. 2007; North et al., 2007; Lewis & Wurtsbaugh 2008; Conley et al., 2009; Moisander et al., 2009; Lewis et al. 2011; Abell et al., 2011; Özkundakci et al., 2011; Paerl et al., 2014; and many others.

Nutrient load and phytoplankton (dominated by cyanobacteria) growth response in Himmerfjärden, Sweden

Courtesy: Ulf Larsson & Ragnar Elmgren
Stockholm University



The Himmerfjärden case: **Baltic ooastal area with large Sewage treatment plant,**

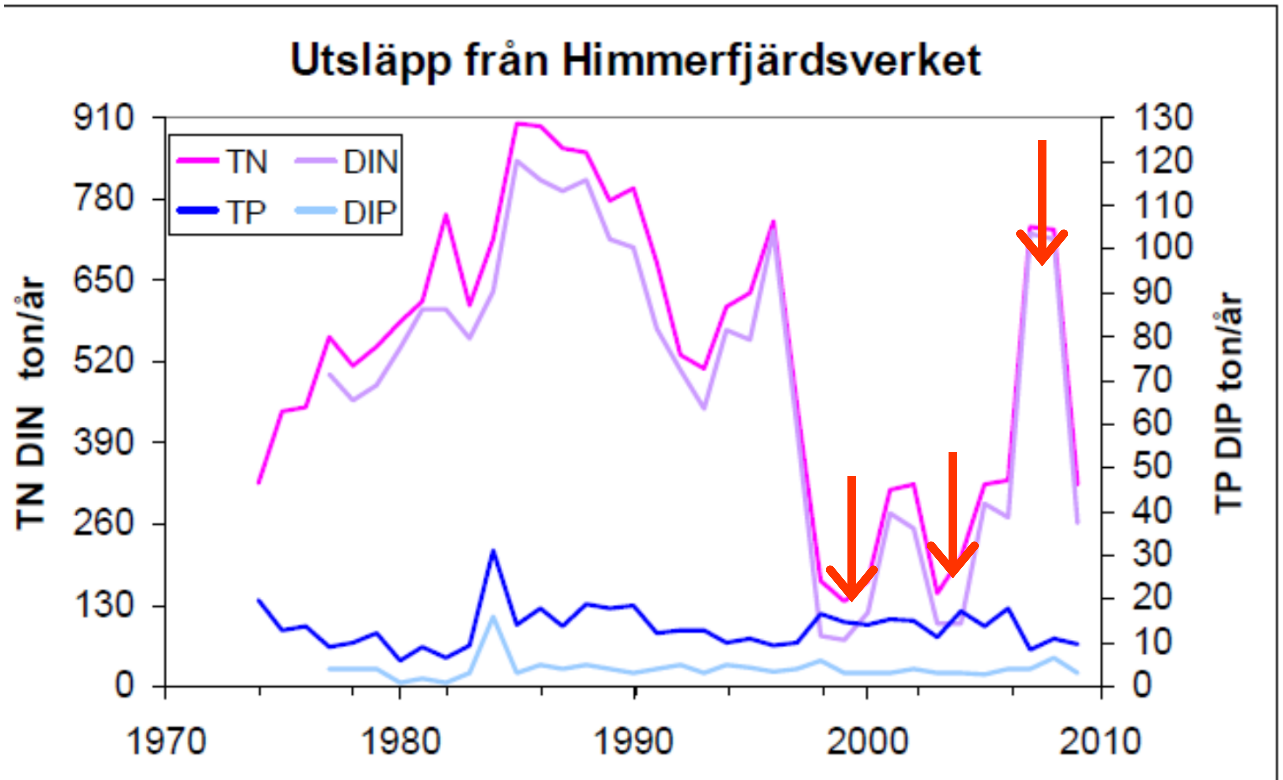
P removal since 1976

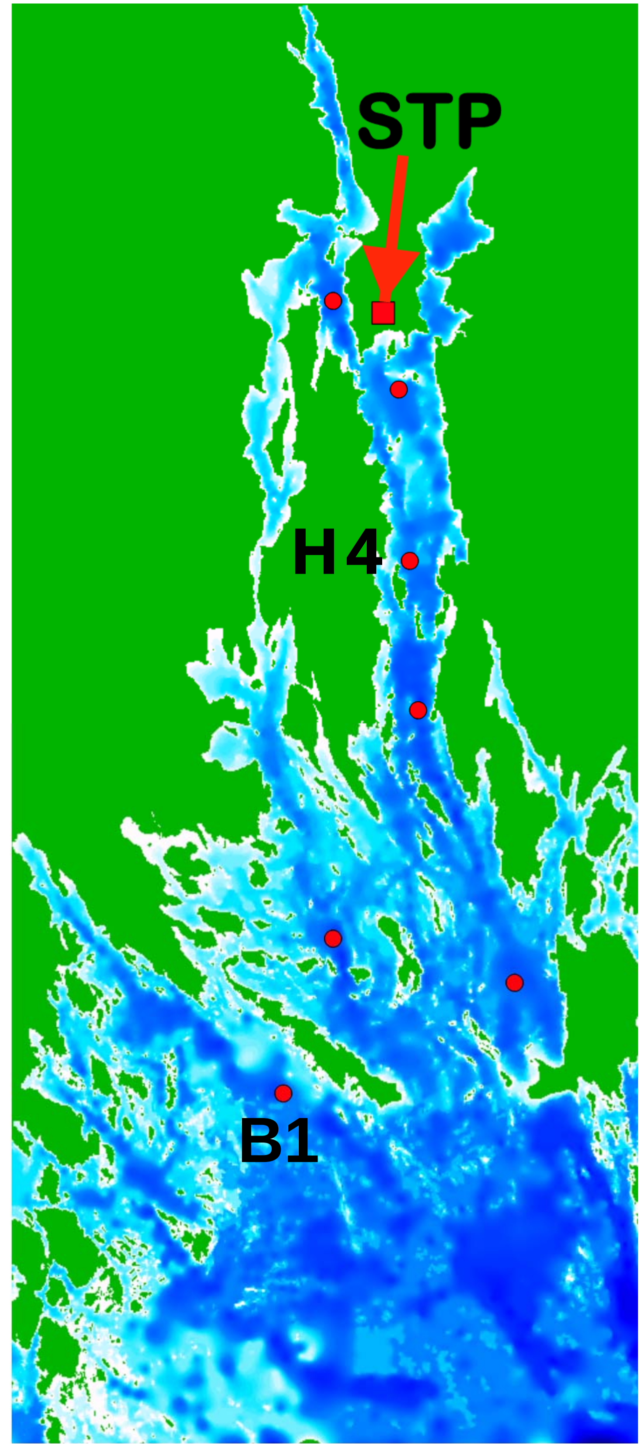
N removal started in 1993 (50%) & 2000 (80%).

No N removal 2004-2008

EFFECTS ON PHYTOPLANKTON (Chl a)?

Plant loads , tonnes/ year

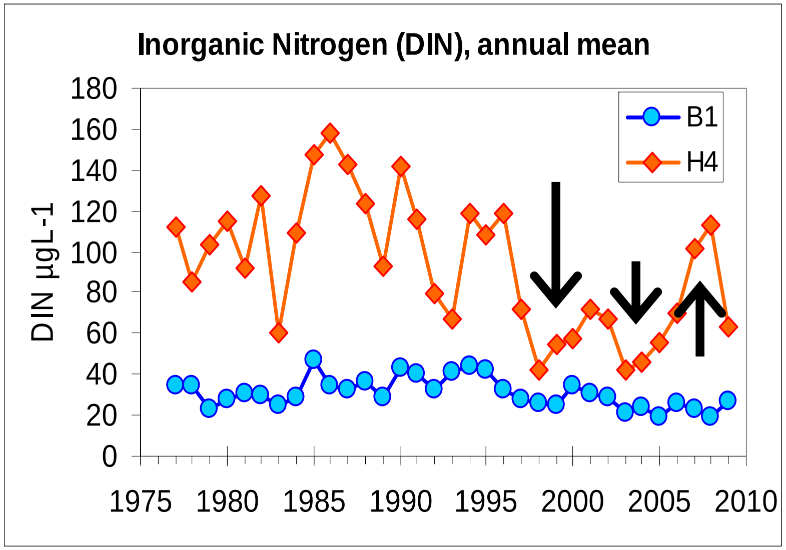


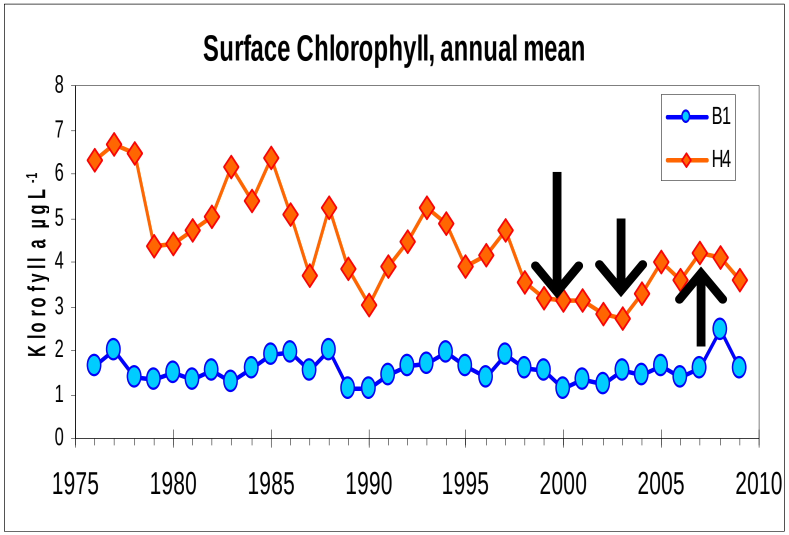


H4 =Eutrophicated station

B1= Reference station

The results: Reducing DIN inputs reduced Chl a and controlled CyanoHABs

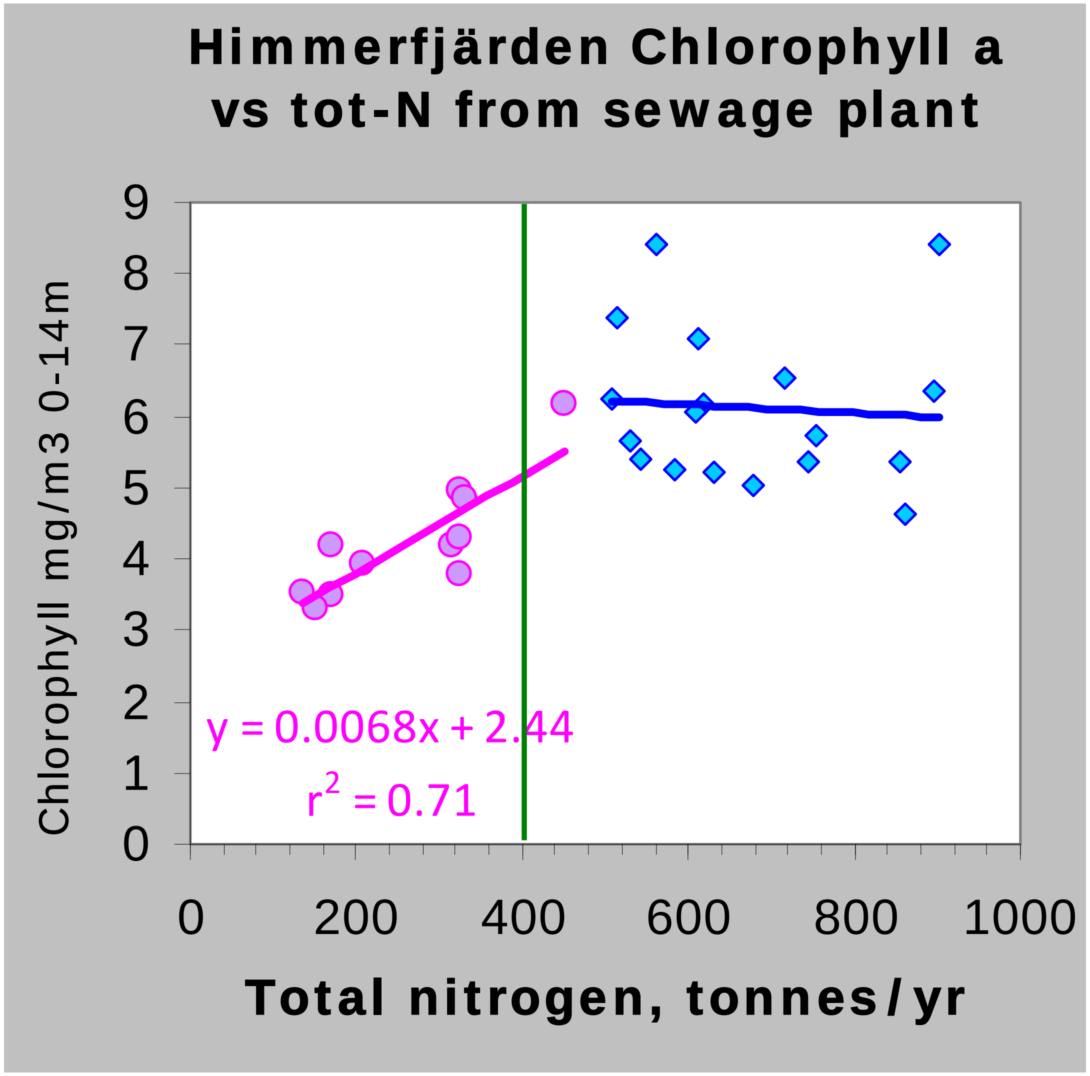




Larsson and Elmgren, In Prep.

Developing a N loading-bloom threshold

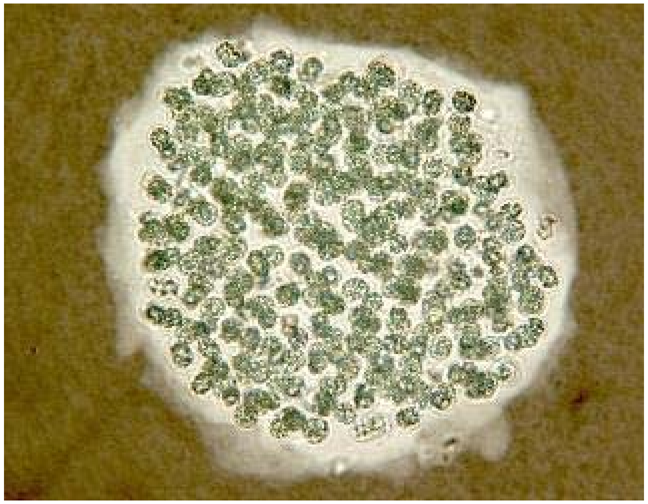
Stockholm University



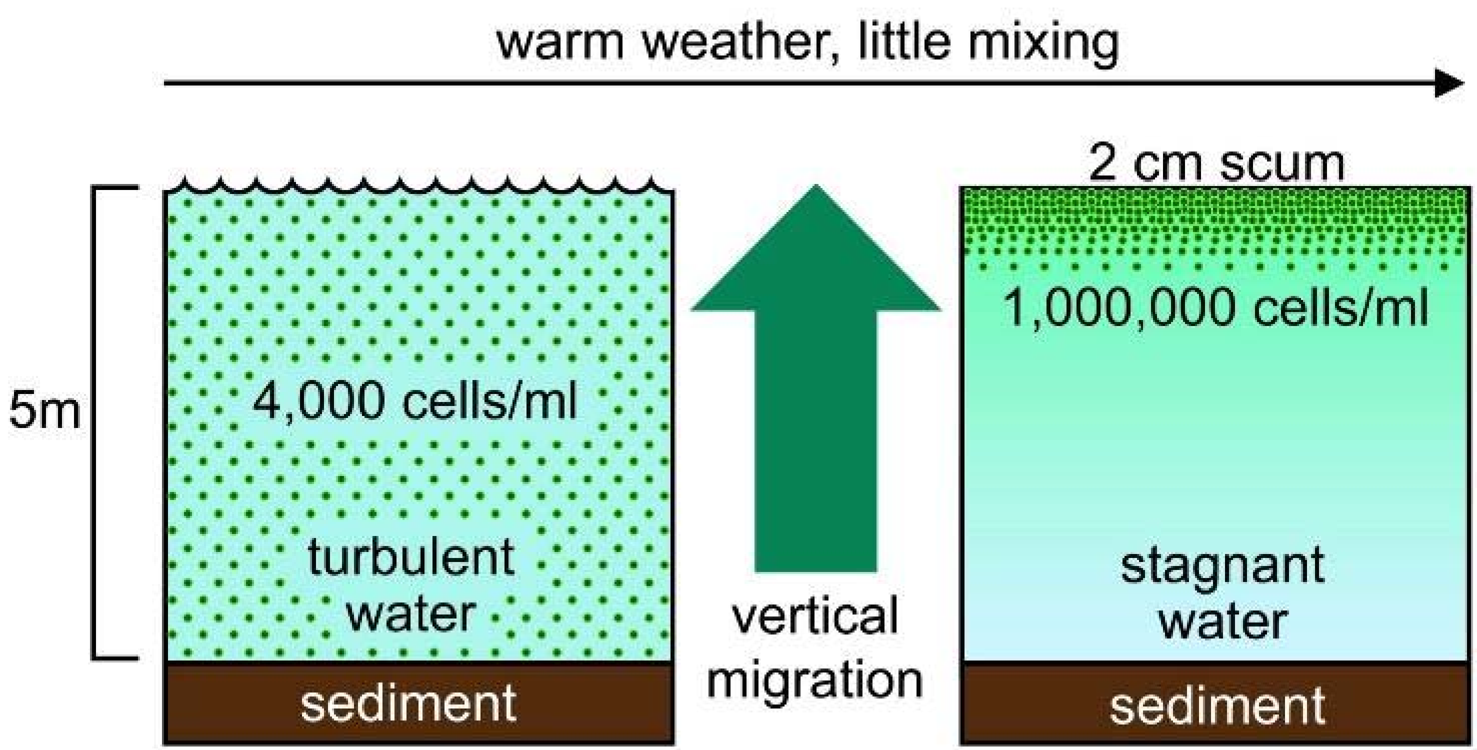
Lowering nitrogen discharge below 400 tonnes/yr clearly reduced local phytoplankton biomass.

Source:
Ulf Larsson, pers.comm.

Additional "twist" due to Climate Change: Its Getting Warmer



Warming leads to stronger vertical stratification……. Buoyant cyanobacteria favored by stronger stratification

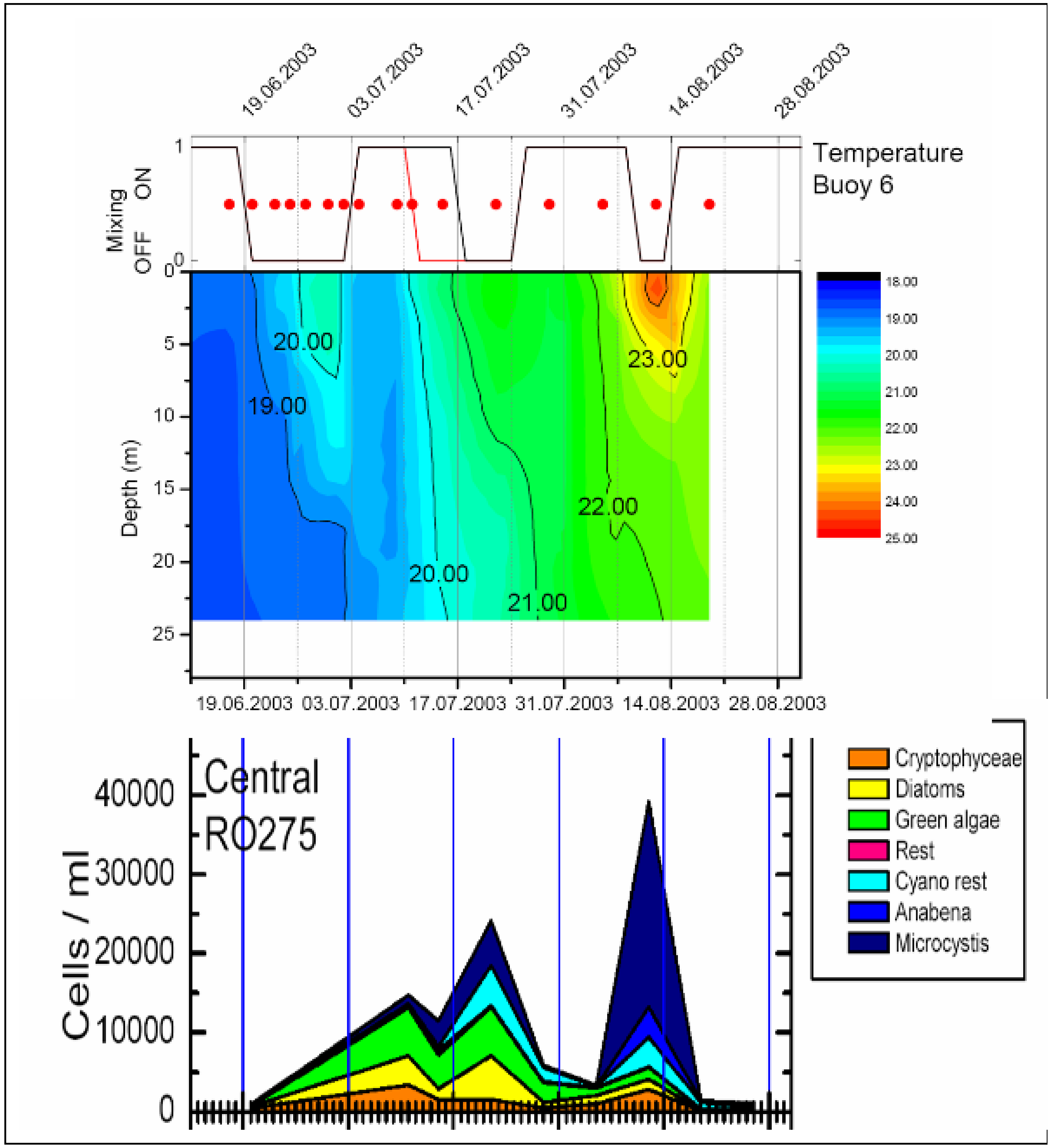


Paerl and Huisman 2009

Example
Mid August 2003:
Lake Nieuwe Meer, Netherlands

Heatwave & little mixing

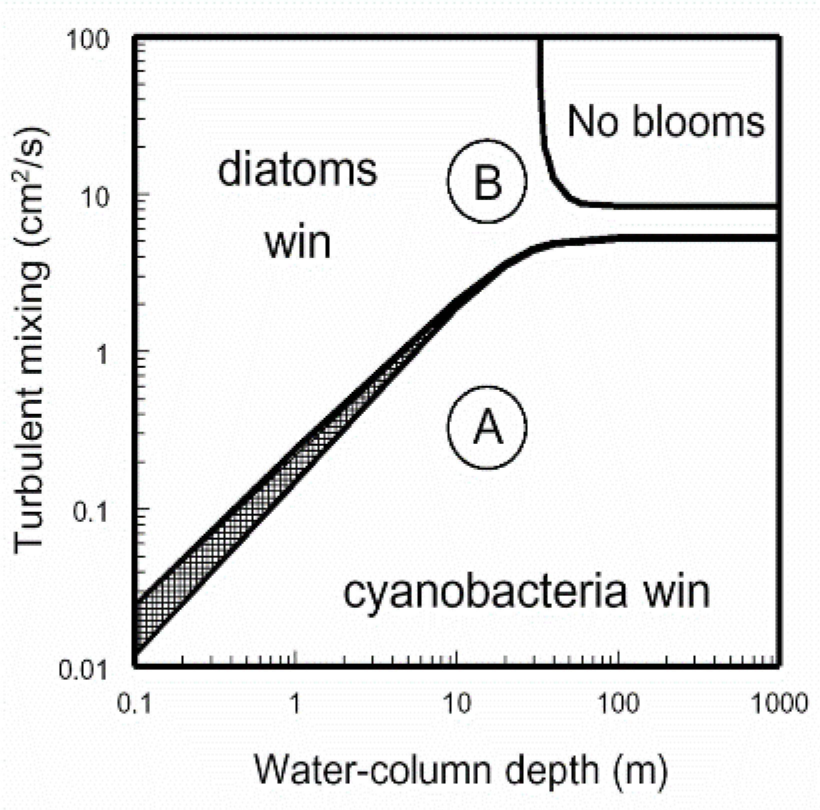
Microcystis benefits!



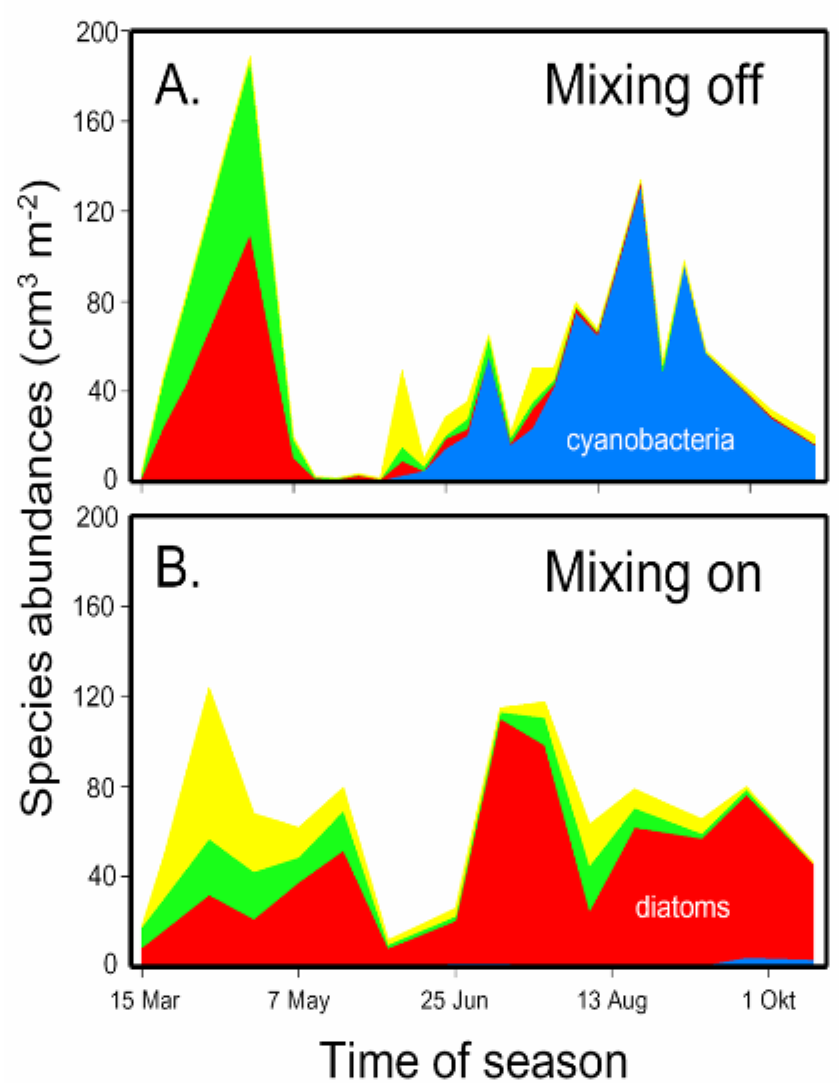
Jöhnk et al., 2008

Testing the Model

Theory

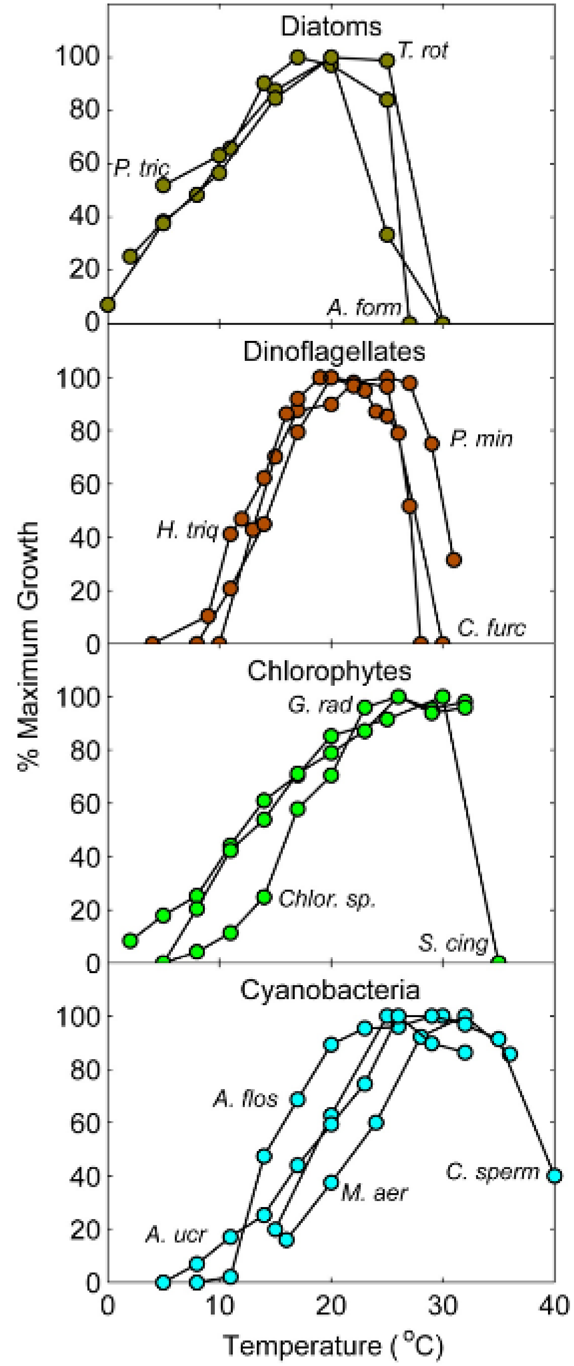


Lake data



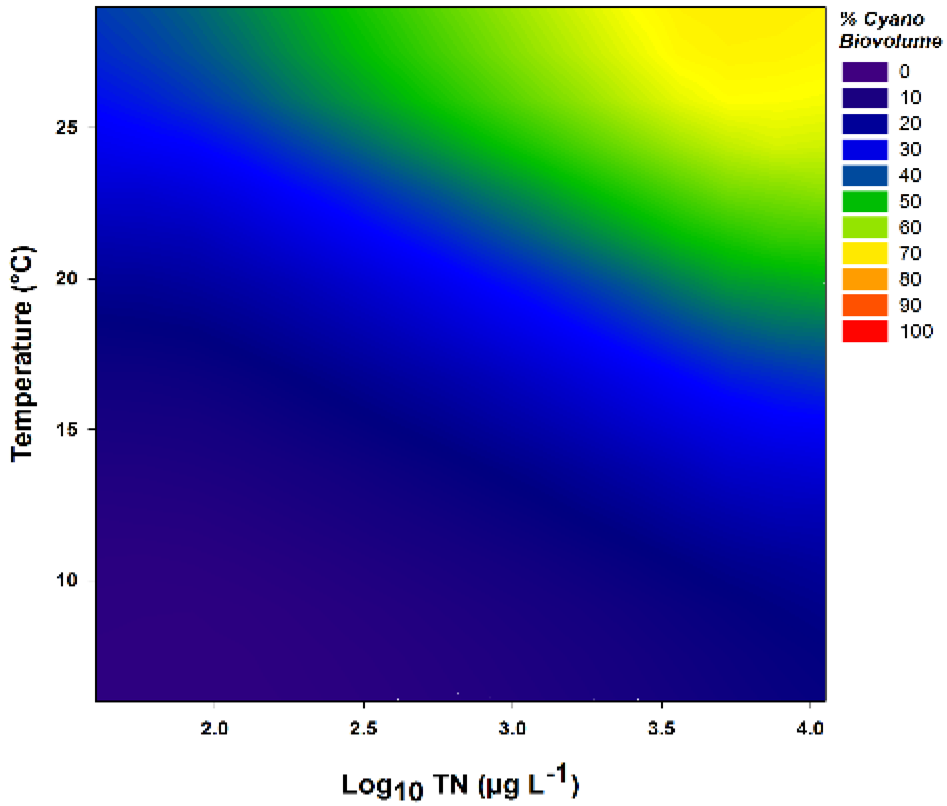
Huisman et al., 2004

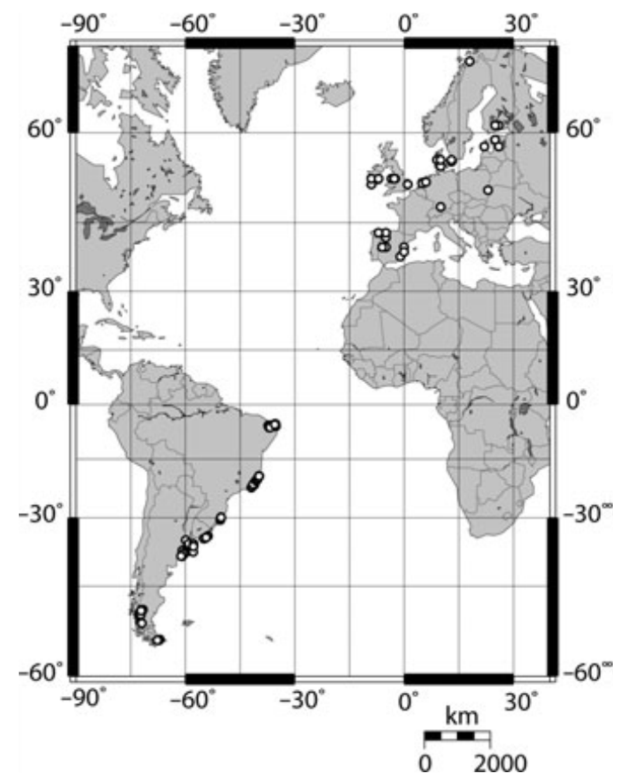
Temperature affects growth rates



Refs.: Kraweik 1982, Grzebyk & Berland 1996; Kudo et al., 2000, Litaker et al., 2002, Briand et al., 2004, Butterwick et al., 2005, Yamamoto & Nakahara 2005, Reynolds 2006

Cyanobacterial dominance along temperature & nutrient (TN) gradients in 143 lakes





Percentage of cyanobacterial biovolume in phytoplankton communities as a function of water temperature and nutrients in 143 lakes along a climatic gradient in Europe and South America.

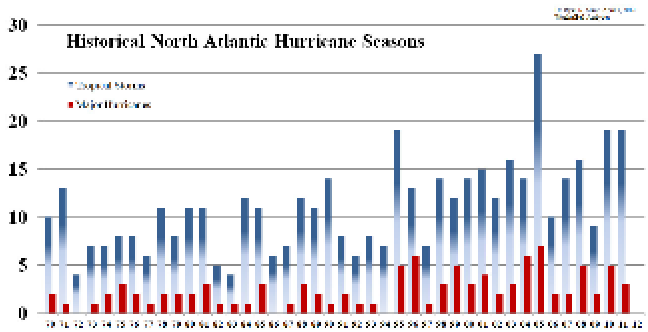
(a) Combined effects of temperature and nutrients as captured by a logistic regression model

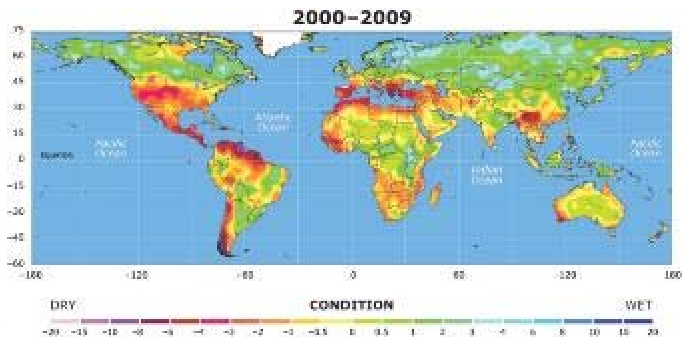
(b) Response surface obtained from interpolation of the raw data using inverse distance weighting.

Data replotted from Kosten et al. (2011). Global Change Biology DOI: 10.1111/j.1365-2486.2011.02488.x

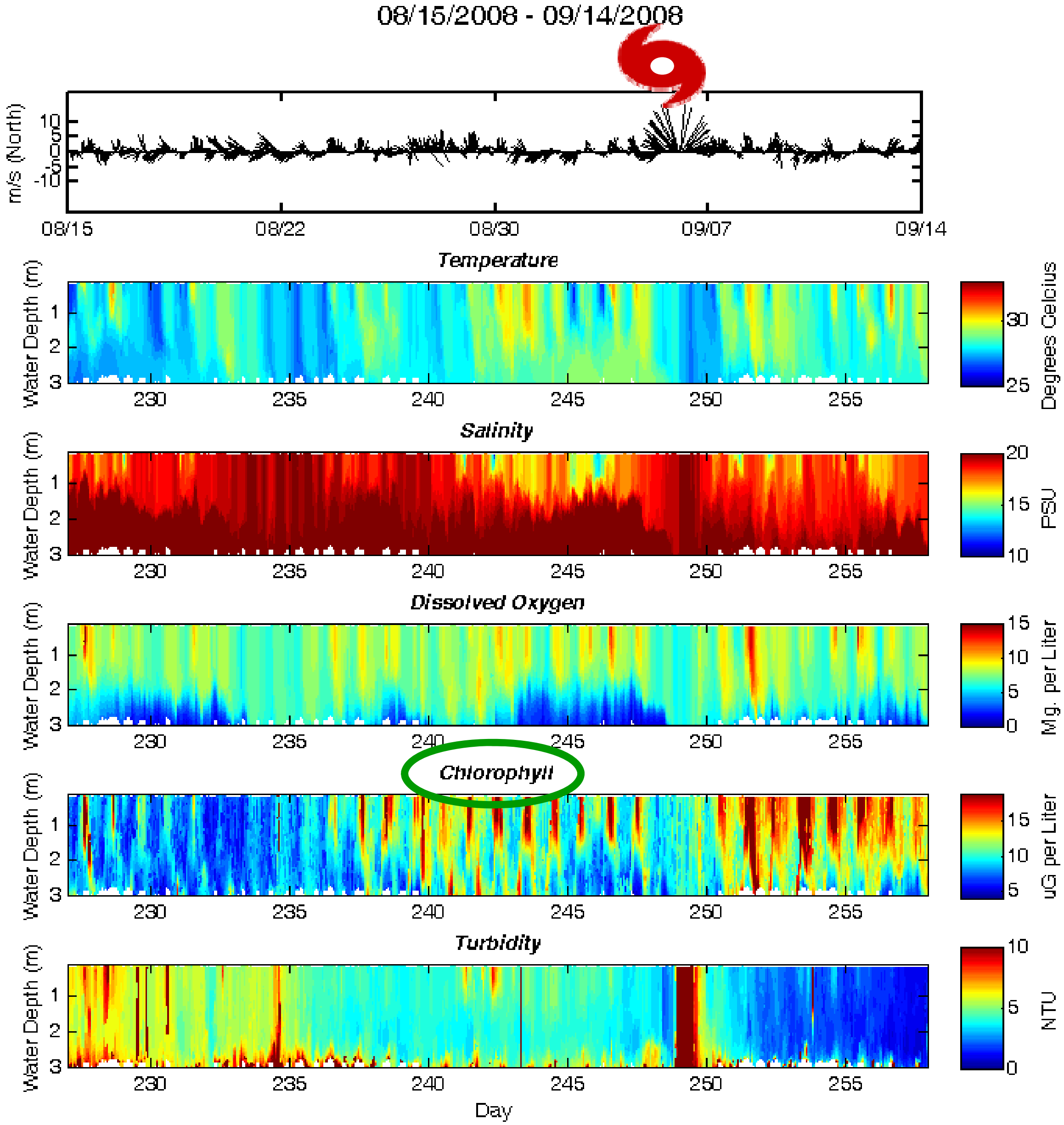
Hydrologically: Things are getting more extreme

- **Storms, droughts more intense, extensive & frequent**



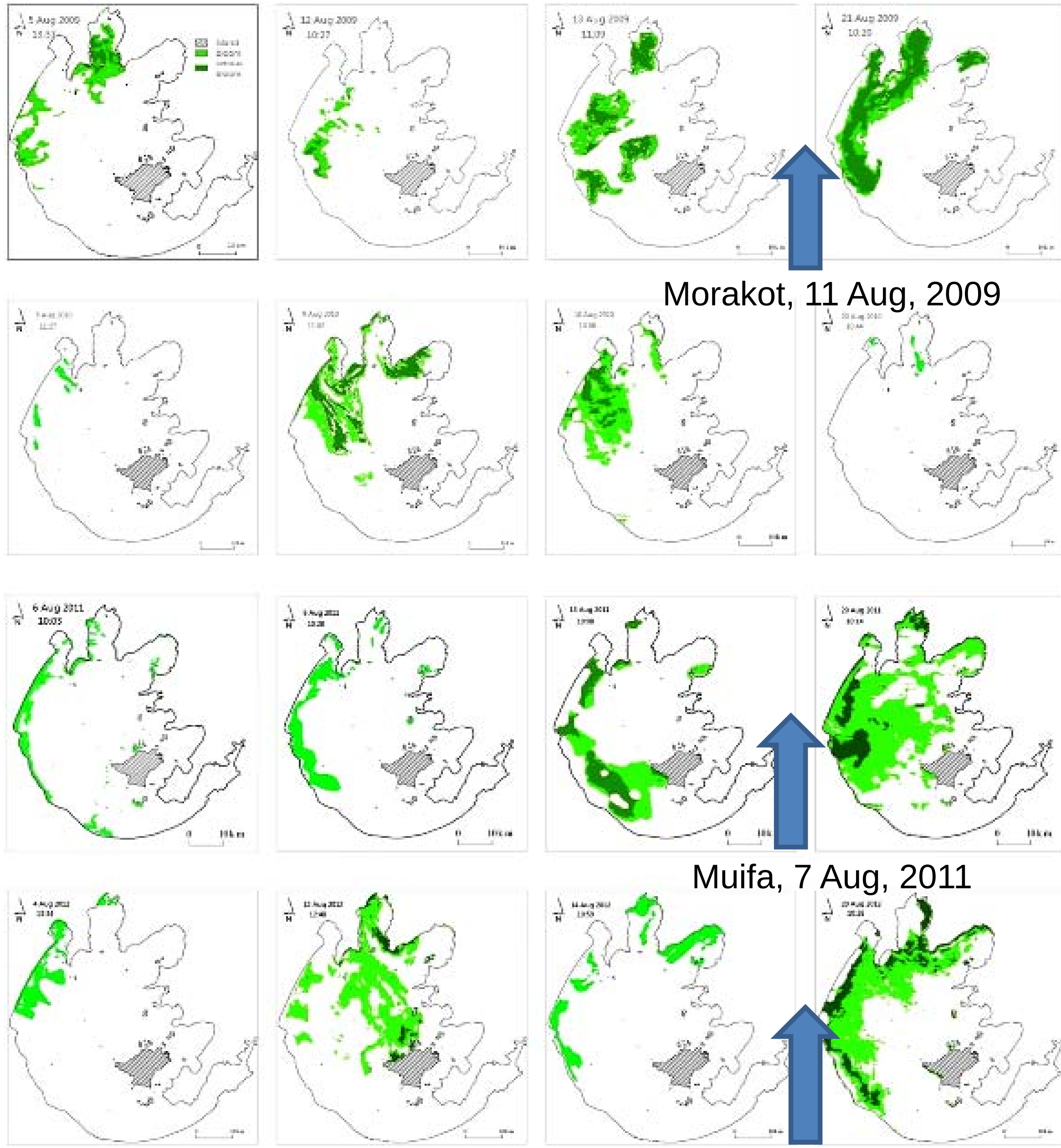


Hydrobiological impacts of Tropical Storm Hanna (8/15/08 – 9/14/08) on The New River Estuary, North Carolina, USA



Impacts of Typhoon Passages on Cyano blooms in Lake Taihu, China, based on MODIS data

(Zhu et al., 2014)



Morakot, 11 Aug, 2009

Muifa, 7 Aug, 2011

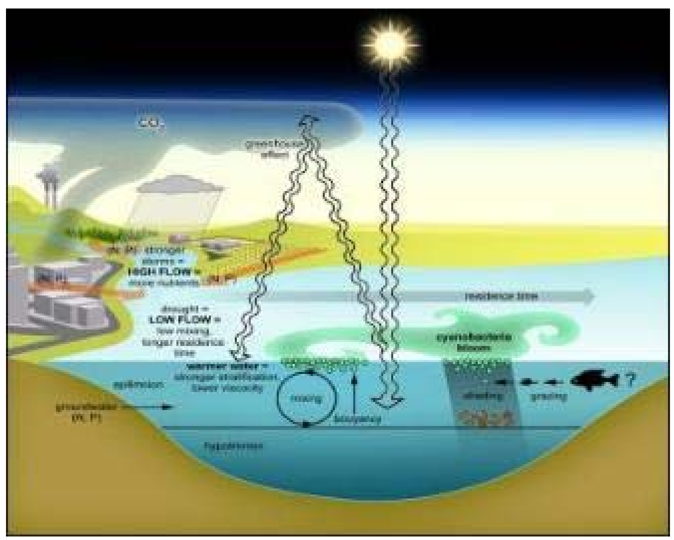
Haikiu, 8 Aug, 2012

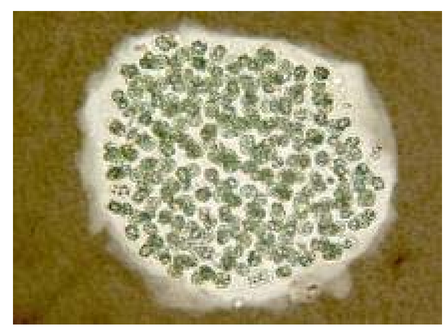
Bottom line: Need nutrient (N&P) input reductions to accompany mechanical/chemical approaches for CyanoHAB mitigation and control

Conclusions/Recommendations

- Reduce <u>both</u> N & P inputs

  - Nutrient-bloom threshold are system-specific
    - In many cases >30% reductions will be needed
  - May need to reduce N and P inputs even more in a warmer world
    - Blooms "like it hot"
- Impose nutrient input restrictions year-round
  - Residence time is long in many lakes (usually > 6 months)
  - Warmer, longer growing seasons





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www.unc.edu/ims/paerllab/research/cyanohabs/

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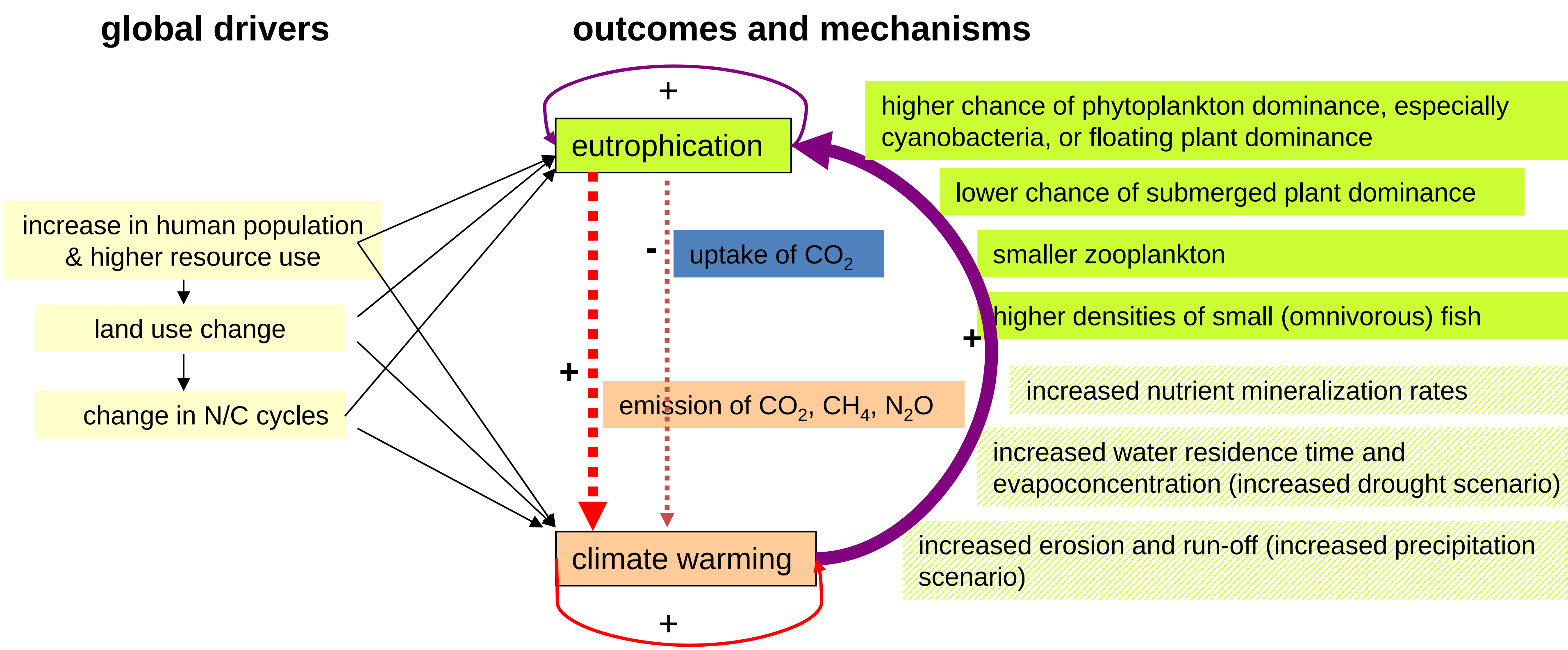
Interacting anthropogenic and climatic drivers of phytoplankton dynamics



green- processes (dashed) that promote eutrophication or its symptoms (filled)

red- processes that promote warming

blue- processes that promote ”cooling”

width of red and blue arrow- relative intensity of effect

dotted arrow- not yet fully quantified

Moss et al. 2011